AS Unit 1: Basic Biochemistry and Cell Organisation

Name:	Date:

Topic 1.5 Nucleic Acids and their functions – Page 5

I. Translation

		Completed
1.	Go through the PowerPoint on Translation and watch the animations (all on the wikispace)	
2.	Read and complete the notes page 2-4	
3.	Have a go at completing the extra sheets p5-8	
4.	Complete the DNA crossword p9, which summarises the DNA work, covered.	
5.	Extra reading on the BioFactsheet and questions are on the wikispace.	

Translation describes the process where that information on the mRNA molecule is used to assemble a polypeptide.

In what part of the cell will translation take place?

The mRNA molecule after it has left the nucleus through a nuclear pore will go and attach itself to a ribosome(s). These ribosomes may be found free-floating or attached to the rough endoplasmic reticulum.

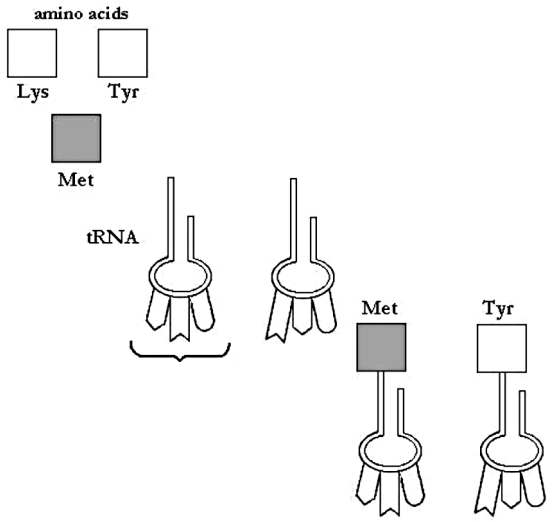
If a polypeptide is being synthesized on the rough endoplasmic reticulum what inferences could you make about what is going to happen to that polypeptide?

In the cytoplasm are free amino acids (the building blocks of polypeptides) and transfer RNA (tRNA) molecules. At one end of each tRNA molecule is a site to which an amino acid can bind.

Label this site.

At the other end are three unpaired bases. The base triplet is called an **anticodon**.
Label the anticodon.

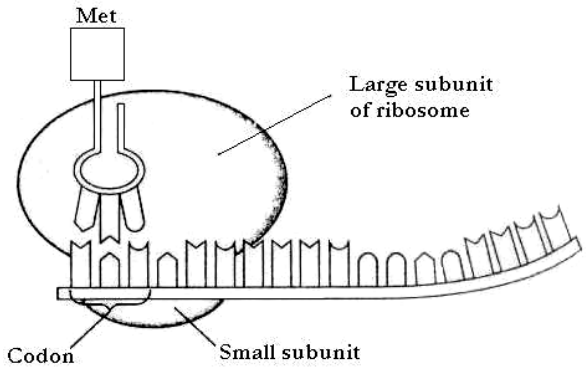
Each tRNA molecule will only bind with a specific amino acid. This process requires energy, which comes from ATP.



The particular amino acid that binds to each tRNA molecule is somehow determined by the anticodon sequence. The actual amino acid is that which would be specified by the nucleotide sequence complimentary to the anticodon, i.e. the codon on the mRNA.

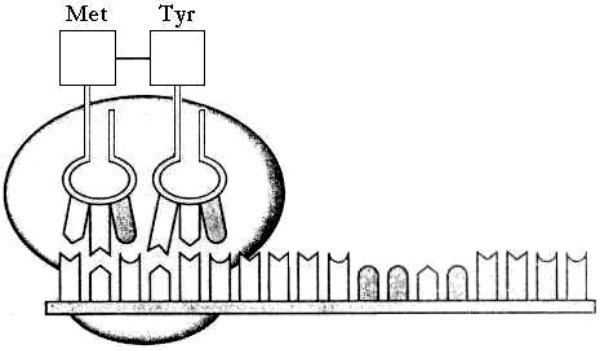
e.g. the codon UCU specifies the amino acid serine. Thus the tRNA molecule that could recognize and bind serine would carry the anticodon AGA.

In the cytoplasm the mRNA molecule attaches to a ribosome. Ribosomes are made of ribosomal RNA (**rRNA**) and protein. They are made up of a small and large subunit.

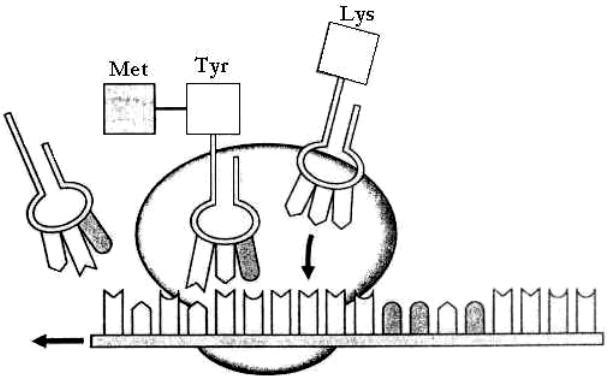


When the mRNA binds to the ribosome 6 bases are exposed. The first three exposed bases, or codon, are AUG. A tRNA molecule with the **complimentary** anticodon , UAC forms hydrogen bonds with this codon.

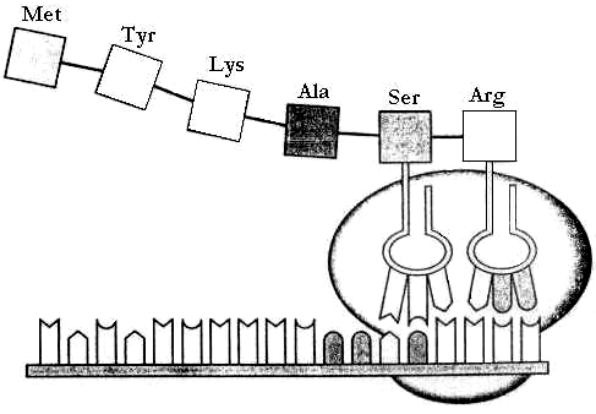
This tRNA molecule has the amino acid methionine attached to it.



A second tRNA molecule bonds with the next three exposed bases. This one brings a different amino acid. The two amino acids are held closely together, and a peptide bond is formed between them.



The ribosome then moves along the mRNA molecule exposing the next three bases on the ribosome. A third tRNA molecule brings third amino acid, which joins to the second one. The first tRNA molecule leaves.



The polypeptide chain continues to grow, until a 'stop' codon is exposed on the ribosome.

Summarize the roles of the following molecules in translation:

mRNA

tRNA

Ribosome

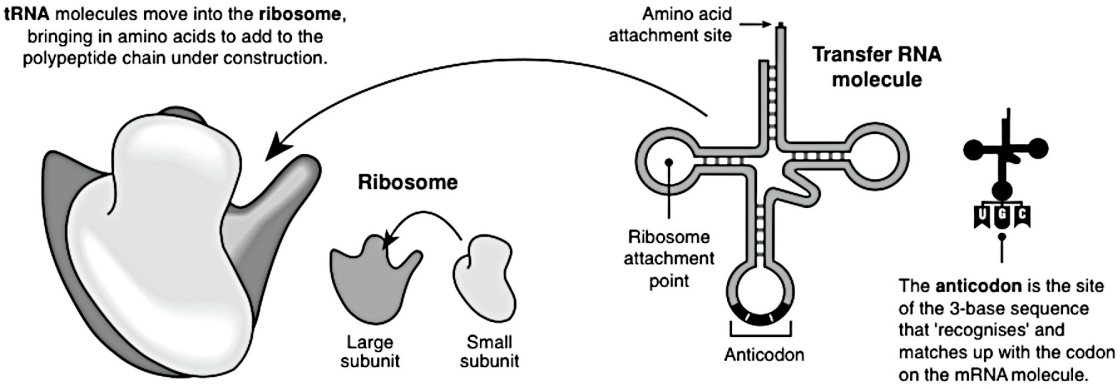
Codon

Anticodon

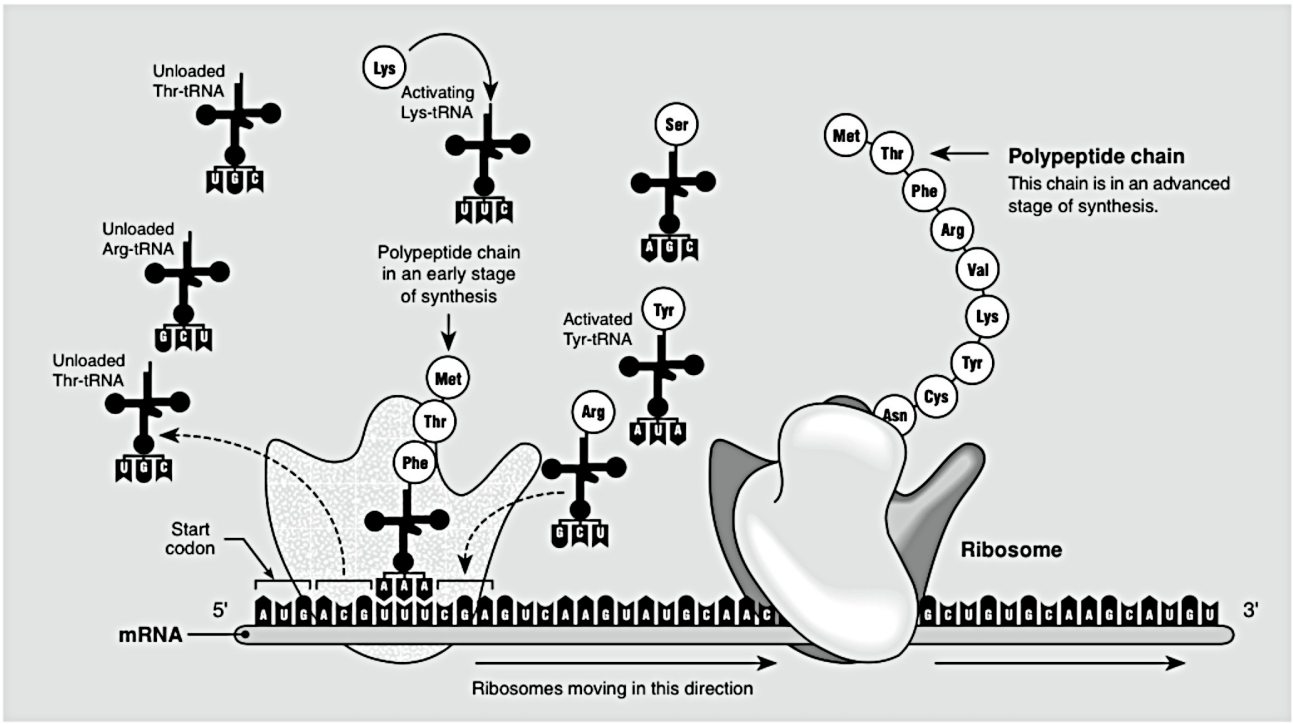
After translation the protein may be further modified and packaged in the Golgi Body.

Translation

The diagram below shows the translation phase of protein synthesis. The scene shows how a single mRNA molecule can be 'serviced' by many ribosomes at the same time. The ribosome on the right is in a more advanced stage of constructing a polypeptide chain because it has 'translated' more of the mRNA than the ribosome on the left. The anti-codon at the base of each tRNA must make a perfect complementary match with the codon on the mRNA before the amino acid is released. Once released, the amino acid is added to the growing polypeptide chain by enzymes.



Ribosomes are made up of a complex of ribosomal RNA (rRNA) and proteins. They exist as two separate sub-units (above) until they are attracted to a binding site on the mRNA molecule, when they join together. Ribosomes have binding sites that attract transfer RNA (**tRNA**) molecules loaded with amino acids. The tRNA molecules are about 80 nucleotides in length and are made under the direction of genes in the chromosomes. There is a different tRNA molecule for each of the different possible anticodons (see the diagram below) and, because of the degeneracy of the genetic code, there may be up to six different tRNAs carrying the same amino acid.



1. For the following codons on the mRNA, determine the **anticodons** for each tRNA that would deliver the amino acids:

   Codons on the mRNA: U A C U A G C C G C G A U U U

   Anticodons on the tRNAs: _____

2. There are many different types of tRNA molecules, each with a different anticodon (HINT: see the *mRNA table*).

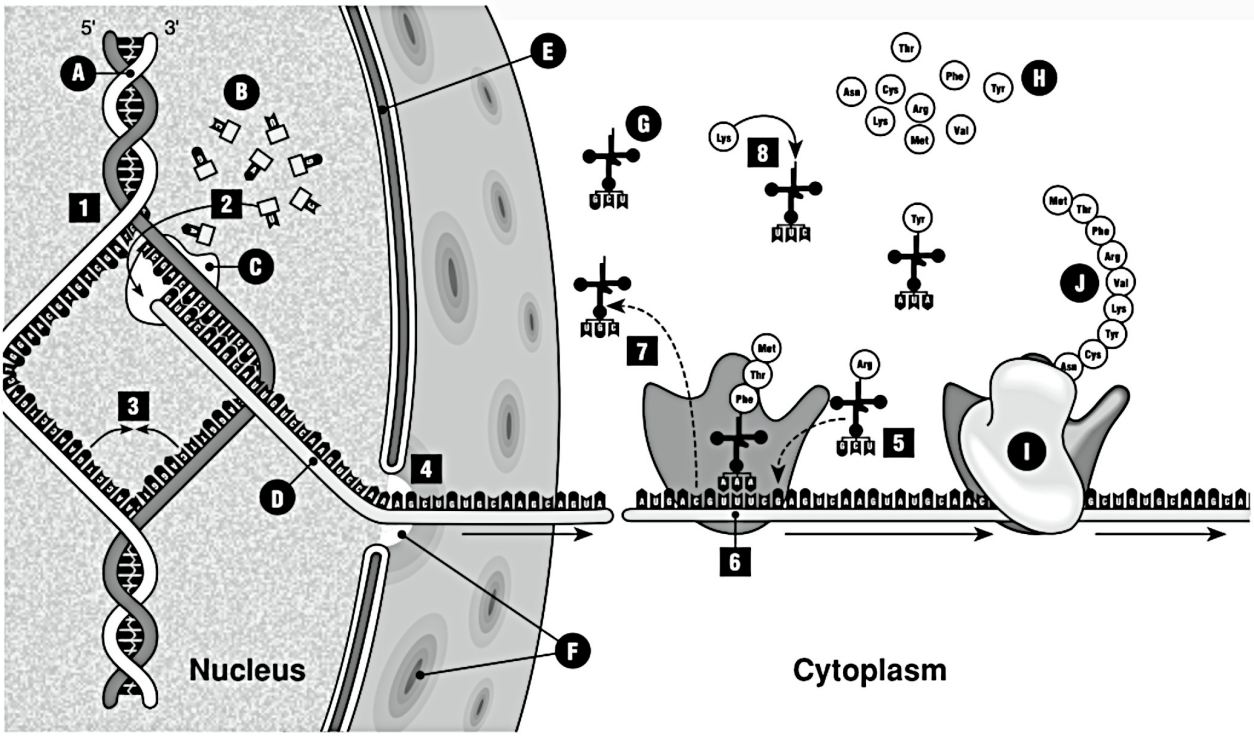
   (a) State how many different tRNA types there are, each with a unique anticodon: _____

   (b) Explain your answer: _____

   _____

   _____

Review of Protein Synthesis



The diagram above shows an overview of the process of protein synthesis. It is a combination of the diagrams from the previous two pages. Each of the major steps in the process are numbered, while structures are labelled with letters.

1. Briefly describe each of the numbered processes in the diagram above:

   (a) Process 1: _____

   (b) Process 2: _____

   (c) Process 3: _____

   (d) Process 4: _____

   (e) Process 5: _____

   (f) Process 6: _____

   (g) Process 7: _____

   (h) Process 8: _____

2. Identify each of the structures marked with a letter and write their names below in the spaces provided:

   (a) Structure A: _____ (f) Structure F: _____

   (b) Structure B: _____ (g) Structure G: _____

   (c) Structure C: _____ (h) Structure H: _____

   (d) Structure D: _____ (i) Structure I: _____

   (e) Structure E: _____ (j) Structure J: _____

3. Describe two factors that would determine whether or not a particular protein is produced in the cell:

   (a) _____

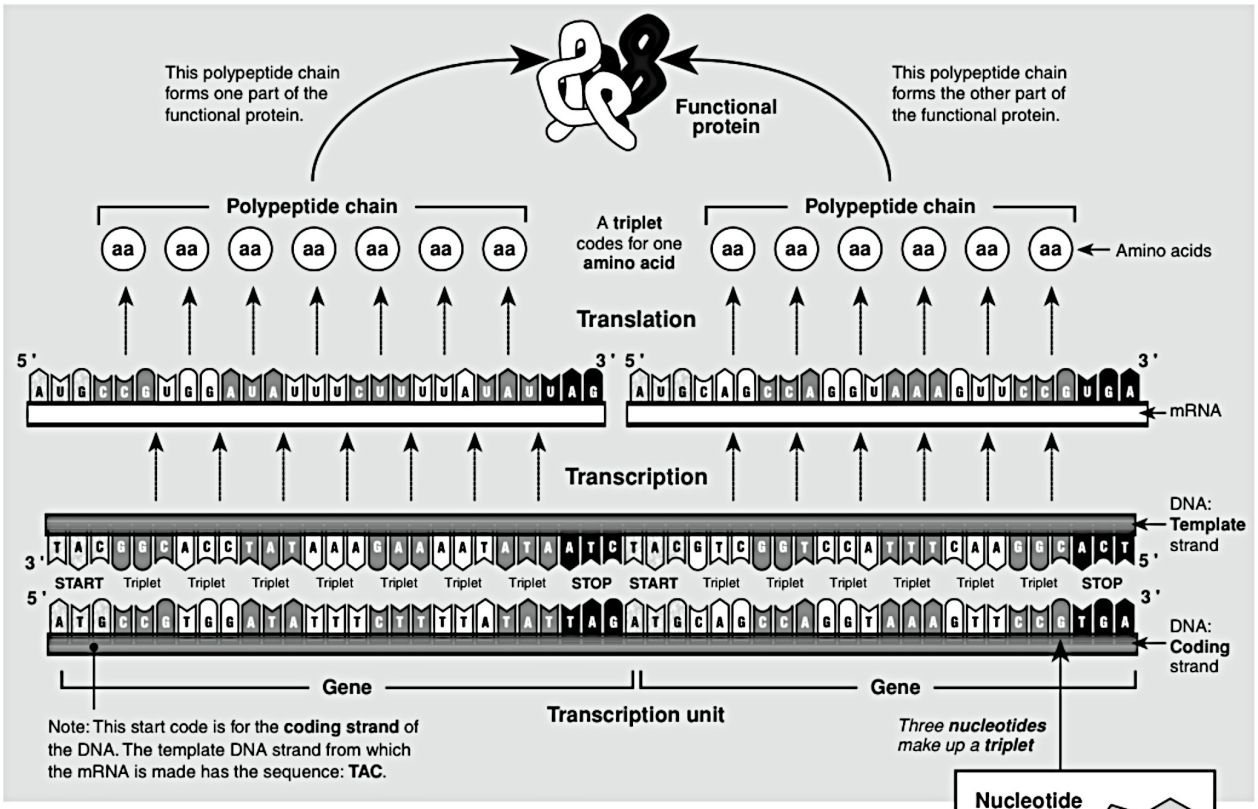
   _____

   (b) _____

   _____

The Simplest Case: Genes to Proteins

The traditionally held view of genes was as sections of DNA coding only for protein. This view has been revised in recent years with the discovery that much of the nonprotein-coding DNA encodes functional RNAs; it is not all non-coding "junk" DNA as was previously assumed. In fact, our concept of what constitutes a gene is changing rapidly and now encompasses all those segments of DNA that are transcribed (to RNA). This activity considers only the simplest scenario: one in which the gene codes for a functional protein. **Nucleotides**, the basic unit of genetic information, are read in groups of three (**triplets**). Some triplets have a special controlling function in the making of a polypeptide chain. The equivalent of the triplet on the mRNA molecule is the **codon**. Three codons can signify termination of the amino acid chain (UAG, UAA and UGA in the mRNA code). The codon AUG is found at the beginning of every gene (on mRNA) and marks the starting point for reading the gene. The genes required to form a functional end-product (in this case, a functional protein) are collectively called a **transcription unit**.



1. Describe the structure in a protein that corresponds to each of the following levels of genetic information:

   (a) Triplet codes for: _____

   (b) Gene codes for: _____

   (c) Transcription unit codes for: _____

2. Describe the basic building blocks for each of the following levels of genetic information:

   (a) **Nucleotide** is made up of: _____

   _____

   (b) **Triplet** is made up of: _____

   _____

   (c) **Gene** is made up of: _____

   _____

   (d) **Transcription unit** is made up of: _____

   _____

3. Describe the steps involved in forming a functional protein: _____

   _____

Further Questions on Protein Synthesis

1. The table below lists the DNA triplets that code for five different amino acids.

DNA triplet	Amino acid
ATG	Tyrosine
TAC	Methionine
CCT	Glycine
TCG	Serine
CGT	Alanine

a. Write down the amino acid sequence coded for by a piece of mRNA with the following base sequence:

A U G A G C G C A G C A U A C G G A

_____

_____

b. A gene mutation resulted in the final mRNA codon changing from GGA to GCA. Name the amino acid coded for by the mutated codon.

_____

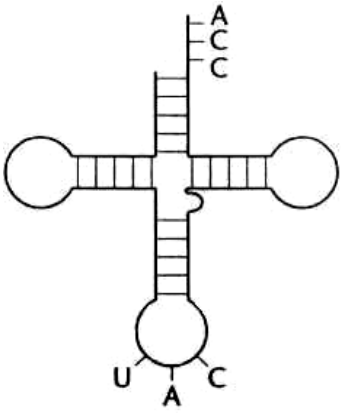
c. Explain how all the possible codons (64) are used in protein synthesis even though there are only twenty amino acids.

_____

_____

d. The diagram below shows a molecule of tRNA.

On the diagram label the following parts:
The anticodon
The point where the amino acid attaches



e. Name the amino acid, which would be carried by this tRNA molecule.

_____

2. Copy the table below and complete each blank box using the information given in the box and an amino acid codon table:

DNA non-coding strand						
Coding strand				TGT		
Transcribed mRNA			AGC			
TRNA anticodon		GUA			UCC	
Amino acid incorporated into the polypeptide.	Tyr					Met

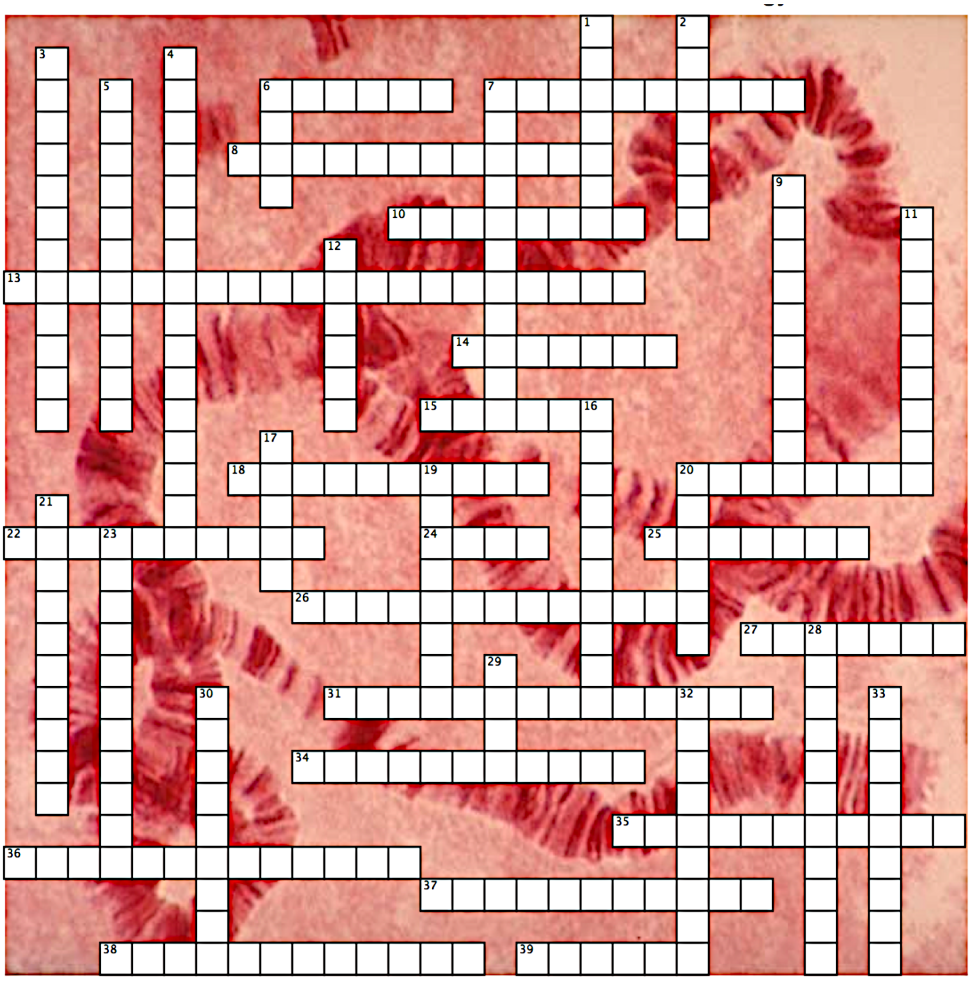
3. For each of the treatments listed below write the letter of the most probable consequence from the list A to F. Note that amantin the toxin of the death cap fungus binds irreversibly with RNA polymerase, and diptheria toxin prevents the movement of ribosomes along the mRNA molecule.

Treatment		**Symptom**	
1	Uracil deprivation	A	Protein synthesis stops immediately, DNA synthesis continues
2	Thymine deprivation	B	DNA synthesis stops, RNA and protein synthesis continue
3	RNA polymerase added	C	Synthesis of DNA, RNA and protein stops immediately.
4	Diptheria toxin added	D	RNA synthesis stops, protein synthesis continues for a few hours.
5	Amantin added	E	Protein synthesis stops, RNA synthesis continues.
6	ATP deprivation	F	No effect

Summary Table of Replication, Translation and Transcription

Feature	Replication	Transcription	Translation
Purpose:			
Location:			
Molecules involved:			

DNA Crossword



Across

6. The entire haploid complement of genetic material in a cell or organism
7. One of a group of nitrogenous bases built on a single ring structure e.g. cytosine, thymine and uracil
8. The opposite strand orientations with which all nucleic acids double-stranded molecules associate
10. A pattern from which a copy can be made
13. DNA synthesis from an RNA template, mediated by reverse transcriptase (2 words: 7, 13)
14. A relatively simple protein associated with DNA in the chromosomes of eukaryotic cells
15. A group of related genes next to each other along the DNA in the nucleus, which produce one or more enzymes
18. An enzyme that catalyses the formation of DNA and RNA molecules

Down

1. The genetic code where each amino acid is specified by three of four bases
2. Any effector molecule that causes the cell to produce larger amounts of the enzymes involved in their metabolism
3. An RNA molecule that functions during translation to specify the sequence of amino acids in forming a polypeptide (2 words: 9, 3)
4. Production of protein from amino acids at the ribosomes in the cytoplasm of cells (2 words: 7, 9)
5. A RNA molecule that transfers an amino acid to a growing polypeptide chain during translation (2 words: 8, 3)
6. In the classic sense, a hereditary unit that occupies a specific locus within the genome or chromosome
7. A molecule consisting of many amino acids linked together in a single chain

Across

20. A part of the DNA molecule to which the RNA polymerase attaches itself, ready to start catalysing the transcription of the genes in an operon
22. The inhibition of transcription when a repressor protein binds to an operator locus on DNA
24. A purine or pyrimidine found in DNA and RNA
25. Made up of one or more chains of amino acids chemically joined together by peptide bonds
26. The production of RNA from DNA in the nucleus
27. The common name for enzymes that join two molecules together with the formation of a new chemical bond
31. The display of gene activity by the synthesis of gene products that affect the phenotype of an organism (2 words: 4, 10)
34. The phase in cell division when the cytoplasm divides and the two cells separate
35. A nucleotide polymer (2 words: 7, 4)
36. One of the twenty naturally occurring amino acids
37. The formation of protein directed by a specific messenger RNA molecule
38. The compaction that takes place as chromosomes enter mitosis
39. Also called an intervening sequence

Down

9. The breaking down of complex molecules by living organisms with release of energy
11. A protein produced by a regulator gene which binds to the operator site on a DNA molecule between the promoter and genes to be transcribed
12. A biological catalyst that speeds up chemical reactions
16. A molecule formed from a nitrogenous base, pentose sugar, and a phosphoric acid
17. The nucleotide triplet in messenger RNA coding for a particular amino acid during protein synthesis
19. Organelle in the cytoplasm of cells where proteins are synthesised
20. One of a group of bases built on a basic two-ring structure, e.g. adenine and guanine
21. The total of all the chemical reactions occurring within a cell or organism
23. The formation of an exact copy of the DNA of the chromosomes prior to cell division
28. The sequence of three bases along the DNA or RNA that specifies the next amino acid in a protein (2 words: 7, 4)
29. The part of a DNA molecule that codes for a protein
30. Either of the two strands of a replicated chromosome while still joined at the centromere
32. The synthesis of a given enzyme in response to a specific inducer
33. A group of three bases next to each other on a tRNA molecule that pairs with a complementary codon of three bases on a mRNA molecule

Bio Factsheet

Number 49

Protein Synthesis II - Mechanisms

Before studying this Factsheet the student should have fully mastered the information in Factsheet Number 22 (Protein synthesis I, April 1998).

This Factsheet summarises the key aspects of the mechanisms of protein synthesis.

1. **The nature of the genetic code.**
2. **The relationships of transfer RNA (tRNA) to amino acids and their role in polypeptide synthesis.**
3. **The roles of messenger RNA (mRNA), rough endoplasmic reticulum(RER) and ribosomes in polypeptide synthesis (transcription and translation).**
4. **The modification of polypeptides into proteins in the RER and Golgi body.**

Questions on this topic usually test knowledge and understanding, by using flow diagram, tick box, 'fill in the missing word' or continual prose questions.

The nature of the genetic code

The genetic code can be found on DNA and on mRNA.

> ***Remember*** *- DNA contains the base thymine but mRNA contains uracil so the letters T or U must be used accordingly.*

This genetic code is universal to all life forms. Fig 1 illustrates the genetic code in its mRNA form.

> ***Exam Hint*** *- A frequent exam error is to say that 'protein synthesis occurs at the ribosomes'. Remember, protein synthesis is a two step process,* ***polypeptide*** *synthesis occurs at the ribosomes, but the assembly of* ***proteins*** *occurs in the spaces of the rough endoplasmic reticulum and Golgi body.*

The triplets of bases shown in Fig 1 are **codons**. A codon is the unit of the genetic code and each codon will always relate to the same amino acid. There are 64 possible codons but only 20 amino acids found in proteins, thus some amino acids have several codons. Because of this, the code is said to be **degenerate** and **redundant.** The code is also **non- overlapping**, meaning that adjacent codons do not share bases.

Fig 1. The genetic code on mRNA

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe UUC Phe UUA Leu UUG Leu	UCU Ser UCC Ser UCA Ser UCG Ser	UAU Tyr UAC Tyr UAA Stop UAG Stop	UGU Cys UGC Cys UGA Stop UGG Trp	U C A G
C	CUU Leu CUC Leu CUA Leu CUG Leu	CCU Pro CCC Pro CCA Pro CCG Pro	CAU His CAC His CAA Gln CAG Gln	CGU Arg CGC Arg CGA Arg CGG Arg	U C A G
A	AUU Ile AUC Ile AUA Ile UUG Met	ACU Thr ACC Thr ACA Thr ACG Thr	AAU Asn ACC Asn AAA Lys AAG Lys	AGU Ser AGC Ser AGA Arg AGG Arg	U C A G
G	GUU Val GUC Val GUA Val GUG Val	GCU Ala GCC Ala GCA Ala GCG Ala	GAU Asp GAC Asp GAA Glu CAG Glu	GGU Gly GGC Gly GGA Gly GGG Gly	U C A G

U = uracil

C = cytosine

A = adenine

G = guanine

It is not necessary to learn this by heart, or to remember the amino acids

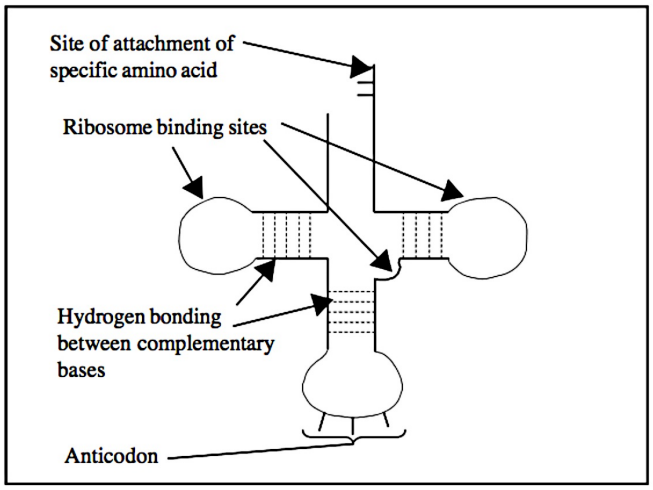
A gene is a length of DNA or mRNA which codes for the assembly of a specific **polypeptide**, and so the sequence of codons which make up the gene will determine the sequence in which amino acids are assembled into that polypeptide. This sequence of amino acids is the **primary structure** of the polypeptide. This will govern how the polypeptide folds and cross bonds into its **secondary structure** (alpha-helix or beta-pleated sheet) and **tertiary structure** (globular form) at the ribosomes, and how it will assemble into its **quaternary structure** (the arrangement and joining of polypeptides together) in the rough endoplasmic reticulum and Golgi body.

Three codons mark the end of genes and are responsible for the release of the polypeptides into the spaces of the rough endoplasmic reticulum. They are referred to as **chain termination codons** or **stop** codons. They may also mark the start of the next gene along the DNA or mRNA molecule.

Typical Exam Question
An interesting task is to imagine that life in another solar system has the same code but that it is overlapping. Compare the polypeptides made from identical base sequences with a non-overlapping code and an overlapping code. One exam board has asked a question on this theme.

tRNA and its roles in polypeptide synthesis
Transfer RNA is found in the cytoplasm. It is about 80 nucleotides long and is clover leaf in shape (Fig 2). There are 20 types of tRNA molecule, one for each amino acid. One end contains a triplet of exposed nucleotides called the **anticodon**, which is complementary to one of the codons found on the mRNA (Fig 1). The other end of the tRNA molecule has a site for the attachment of a specific amino acid. The amino acid which becomes attached must correspond to the anticodon at the other end, and thus also to the codon on the mRNA.

Fig 2. The structure of tRNA



***Remember - Transcription** is the copying of genentic code from DNA onto mRNA. **Translation** is the assembly of a polypeptide from the genetic code on the mRNA.*

Each molecule of tRNA thus picks up its own amino acid, and by matching its anticodon to the complementary codon on the mRNA the amino acids can be assembled into the correct sequence.

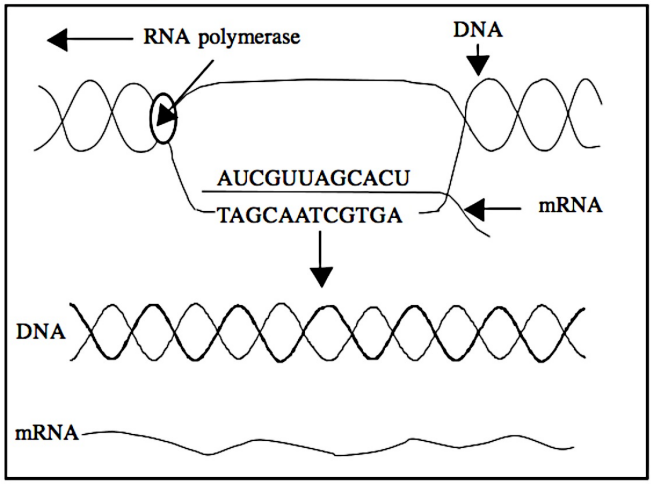
***Remember** - complementary bases will join by hydrogen bonding, A to U or A to T and C to G. This is essential knowledge to work out some exam answers.*

Before amino acids can join with tRNA they have to be activated using ATP as an energy source. The activation and combination with tRNA occurs in the cytoplasm. Thus protein synthesis is an **anabolic** or energy requiring process.

The roles of mRNA and ribosomes in polypeptide synthesis
The genetic code on the DNA is passed onto mRNA by a process of **transcription**. In this process the DNA helix unwinds for the part of its length which contains the genes to be copied, and one of its strands (called the coding strand) acts as a template for the synthesis of a complementary single strand or mRNA. The enzyme **RNA polymerase** catalyses the process.

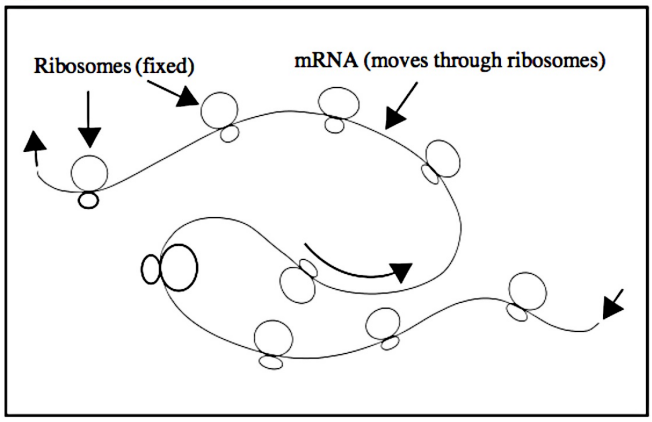
The process of transcription is shown in Fig 3. The mRNA is synthesised from free complementary nucleotides in the surrounding nuclear sap.

Fig 3. Transcription of mRNA from DNA



After transcription the DNA returns to its double stranded form and the new mRNA passes through the pores in the nuclear membrane into the cytoplasm to become associated with the ribosomes that are fixed on the rough endoplasmic reticulum. Fig 4 shows the association between mRNA and ribosomes.

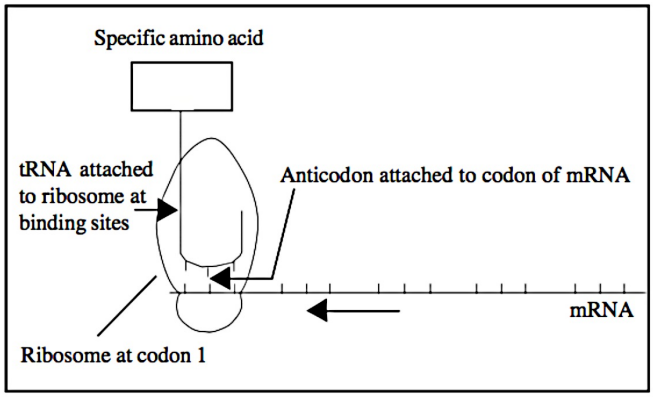
Fig 4. Ribosomes and mRNA



The process of **translation** can now take place. This is the synthesis of a specific polypeptide by the ribosomes using the genetic code on the mRNA to assemble the amino acids in the correct sequence.

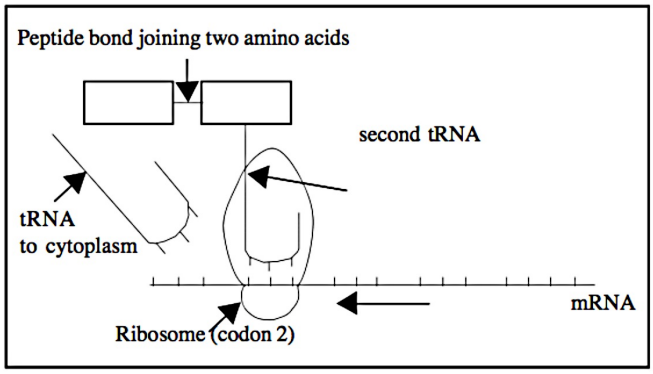
In the first step of translation codon 1 of the first gene is covered by the ribosome. This enables the complementary tRNA to attach to the codon with its anticodon, by hydrogen bonding and so the first specific amino acid is brought into place (Fig 5).

Fig 5. Translation Step 1



In the second step of translation the mRNA moves so that codon 2 of the gene is covered by the ribosome. This enables the second tRNA molecule to attach to the second codon by an anticodon-codon link and so the second specific amino acid is carried into place. The enzyme **peptide synthetase** in the ribosome catalyses the condensation reaction to form a **peptide bond** to join the first and second amino acids into a dipeptide. The first tRNA molecule is then released back to the cytoplasm for reuse (Fig 6).

Fig 6. Translation Step 2



Similar steps are repeated as each successive codon of the gene is covered by the ribosome, and so a polypeptide is assembled, the amino acid sequence of which is related to the codon sequence of the gene. At the end of the gene is a chain termination (stop) codon. When this is covered by the ribosome there is no complementary tRNA to join the codon and so the synthesised polypeptide is released into the spaces of the rough endoplasmic reticulum. The process of translation then proceeds along gene 2 of the mRNA.

***Remember** - It is now known that the ribosome covers two codons of the mRNA at a time.Thus two tRNA molecules with their amino acids can be held in place while a peptide bond forms.*

The process of polypeptide synthesis is **amplified** by having the length of mRNA attached to several or many ribosomes at a time so that they can all carry out translation at the same time. Such an assembly of mRNA and ribosomes attached to the rough endoplasmic reticulum is called a **polyribosome**. The same length of mRNA can pass through the same assembly of ribosomes time and time again. The polyribosomes in an activated plasma cell enable the production of around 2000 antibody molecules per cell per second for 4 to 5 days.

(The mRNA and associated ribosomes illustrated in Fig 4. is a polyribosome system).

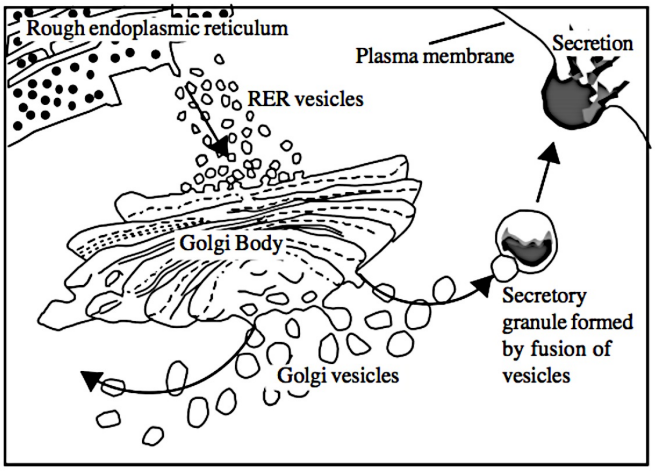
Modification of polypeptides into protein

The synthesised polypeptides are transferred to the Golgi body in vesicles which bud off from the rough endoplasmic reticulum, migrate through the cytoplasm and fuse with the cisternae (cavities) of the Golgi body. Here (and also in the rough endoplasmic reticulum and its vesicles) the polypeptides couple by hydrogen bonding and sulphur bonding, between amino acid side chain groups, to form proteins. Examples of proteins formed in this way are **lysozyme** and **catalase**.

The Golgi body also allows the assembly of other protein derivatives. For instance, carbohydrates may be joined to proteins to make **glycoproteins** such as mucus, lipids may be joined to proteins to make **lipoproteins,** iron containing haem groups may be joined to proteins to make molecules such as **haemoglobin, myoglobin** and **cytochromes.**

The products of the Golgi body are budded off as Golgi vesicles.They either remain in the cytoplasm as, for example, lysosomes (containing lysozyme) and peroxisomes (containing catalase), or fuse together into secretory granules. These can then fuse with the plasma membrane to secrete their contents out of the cell, for example, antibodies, plasma proteins, digestive system enzymes. This process is called **exocytosis**. The functions of the Golgi body are shown in Fig 7.

Fig 7. The functions of the Golgi body



Practice Questions

1. Read through the following account of protein synthesis and then fill in the spaces with the most **appropriate word or words.**

   Messenger RNA formed by _____ from the nuclear DNA passes through pores in the _____ and attaches to _____ fixed to the _____. _____ amino acids are brought to the mRNA by the molecules of _____ which attach to the _____ of the mRNA by their _____. Adjacent amino acids then join by _____ to form a _____. These assemble into proteins either in the spaces or vesicles of the _____ or are transported to the _____ for assembly there.

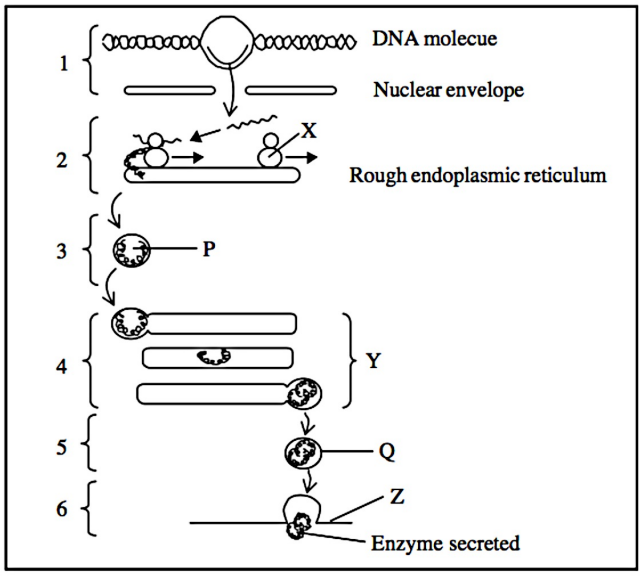
   (12 marks)

2. The table below refers to some features of mRNA and tRNA. If a feature is correct mark the relevant box with a tick and if it is incorrect mark the box with a cross.

Feature	mRNA	tRNA
Contains anticodons		
May contain several genes or alleles		
Has a clover leaf shape		
Can associate with any amino acid		
Contains uracil instead of thymine		
A short molecule 70 –90 nucleotides long		

. (6 marks)

3. The diagram below shows some of the stages involved in the secretion of an enzyme by a stomach cell. The stages are labelled 1 to 6.



(a) Name the structures X, Y and Z.

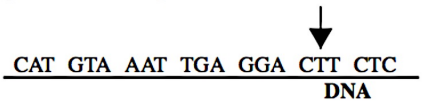
(b) Name the processes occuring in stages 1, 2, 4 and 6.

(4 marks)

(c) Distinguish between vesicles P and Q and their contents.

(4 marks)

4. The following sequence of codons is from the gene on DNA which codes for part of the haemoglobin molecule.



(a) Using the genetic code shown on page I work out the haemoglobin gene codons on the mRNA and the sequence of amino acids found in the haemoglobin molecule.

(3 marks)

(b) If the DNA base T, marked with an arrow was substituted with A, how would the haemoglobin chain differ?

(1 mark)

Answers

Semicolons indicate marking points.

1. transcription; nuclear membrane; ribosomes; rough endoplasmic reticulum; specific; tRNA; codons; anticodons; peptide bonds/ condensation/peptide links; polypeptide; rough endoplasmic reticulum; Golgi body;

2.

Feature	mRNA	tRNA
Contains anticodons	✗	✓
May contain several genes or alleles	✓	✗
Has a clover leaf shape	✗	✓
Can associate with any amino acid	✗	✗
Contains uracil instead of thymine	✓	✓
A short molecule 70 –90 nucleotides long	✗	✓

3. (a) X = ribosome; Y = vesicle of RER;
   Z = Golgi vesicle;

   (b) 1 = transcription; 2 = translation;
   4 = protein assembly/modification;
   6 = exocytosis;

   (c) P is a vesicle from the rough endoplasmic reticulum;
   Q is a vesicle from the Golgi body;

   P contains polypeptides/proteins assembled in RER:
   Q contains proteins assembled in Golgi body/modified proteins/ glycoproteins/any correct example;

4. (a) GUA CAU UUA ACU CCU GAA GAG;;
   (deduct 1 mark per error)

   Val His Leu Thr Pro Glu Glu ;

   (b) last but one amino acid/penultimate amino acid would be valine/ Val instead of glutamic acid/Glu;

Acknowledgements;
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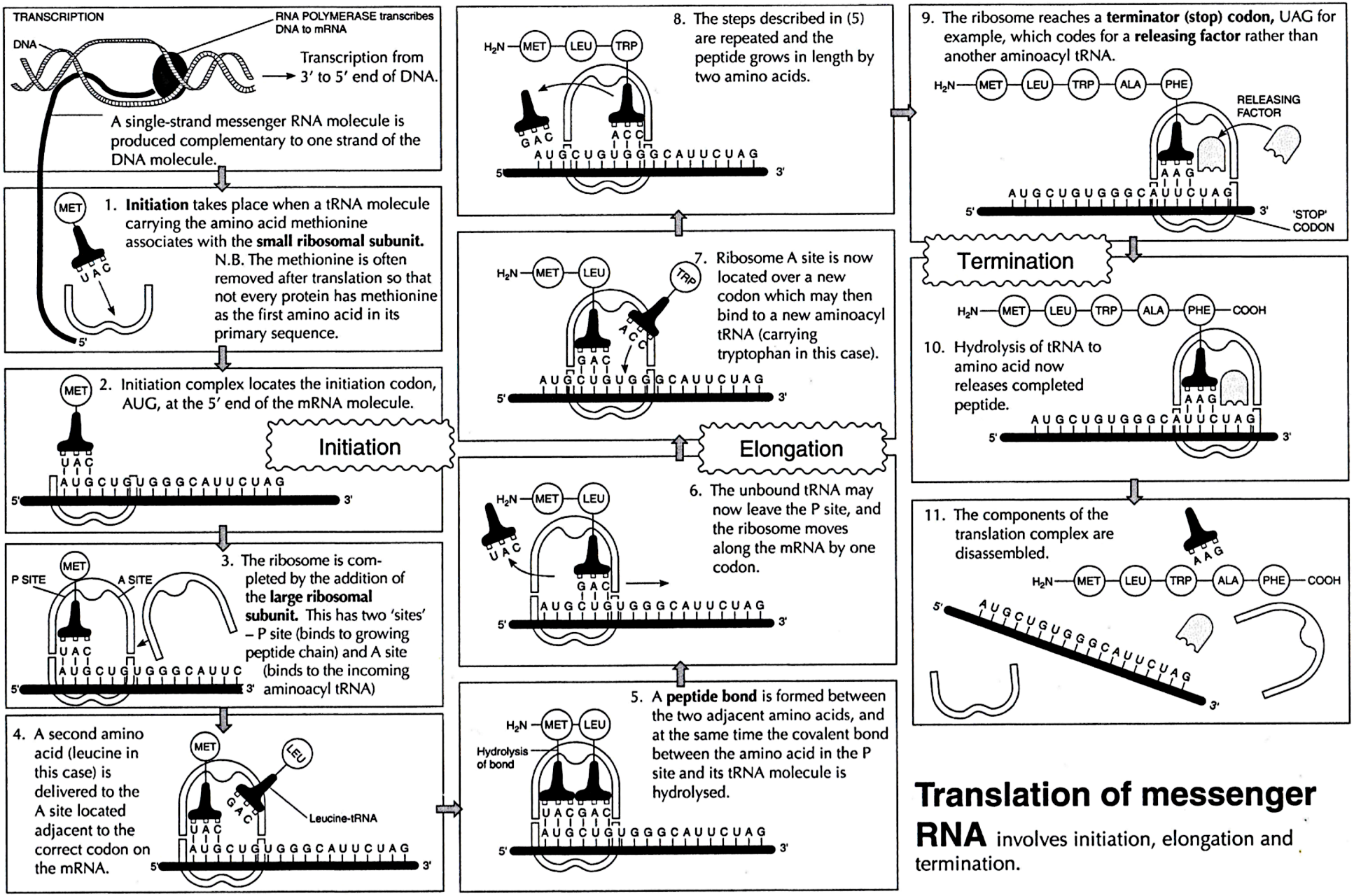

Translation of messenger RNA involves initiation, elongation and termination.